

HADRONISATION AT LEP

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An overview of recent results from LEP concerning the hadronisation process is presented. Emphasis is placed on the b -quark. The first presented analysis is the measurement of the b -quark fragmentation function. It includes a new, hadronic-model independent method to extract the x -dependence of the non-perturbative QCD component from the measured fragmentation function. This is followed by the results of two analyses on, respectively, production rates of b -excited states and branching fractions of b -quarks to neutral and charged b -hadrons. Multiplicity in the final state is also discussed concerning the difference in multiplicities between b and light quark initiated events, and total multiplicities in three jet events. Finally, recent measurements of ω and η meson production rates are given.

1 b -Quark Fragmentation Function

1.1 LEP Measurements

The b -quark fragmentation function in e^+e^- collisions is commonly defined as the distribution of the scaled energy $x = \frac{E_B}{E_{beam}}$ variable, where E_B is the energy taken by the weakly decaying b -hadron. New measurements of the fragmentation function at or near the Z^0 pole are now available from ALEPH ¹, DELPHI (preliminary) ², OPAL ³, and SLD ⁴. These results are presented in Figure 1. The different collaborations chose different methods for the reconstruction of the b -hadron's energy and for the unfolding of the underlying x from the measured one. This measurement is affected by the control of the finite resolution of the detector, which also gives the main systematic uncertainty.

1.2 Extraction of the Non-Perturbative QCD Component

The b -quark fragmentation function is generally viewed as resulting from three components: the primary interaction (e^+e^- annihilation into a $b\bar{b}$ pair in the present study), a perturbative QCD

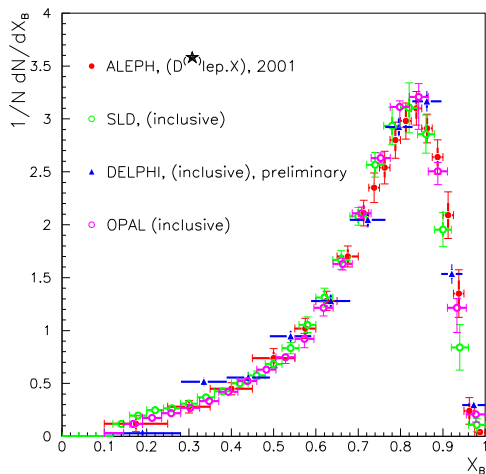


Figure 1: Unfolded x distributions from ALEPH, DELPHI, OPAL and SLD.

component (PC) describing gluon emission by the quarks and a non-perturbative QCD component (NPC) which incorporates all mechanisms at work to bridge the gap between the previous phase and the production of weakly decaying b -mesons. The PC can be obtained using analytic expressions or Monte Carlo generators. The NPC is usually parametrised phenomenologically via a model. A method is proposed to extract the NPC directly, and independently of any hadronic physics modelling⁵. The extraction has been done using some of the measurements of the b -quark fragmentation function mentioned in Section 1.1. The method employs direct and inverse Mellin transformation. Its detailed description is outside the framework of this paper, and therefore we would concentrate on results. The extracted NPC depends only on the way the PC has been defined.

The method has been applied using two different approaches to evaluate the PC: a parton shower Monte-Carlo, and an analytic NLL computation⁶. In both cases, the extracted functions have been found to be zero for $x < 0.7$. This means that the gluon radiation is well accounted, in this region, by both approaches. Results for the extracted NPC and comparisons with distributions from known hadronisation models, that have been fitted to the ALEPH data¹, are shown in Figure 2. When the PC is taken from a parton shower Monte-Carlo, the NPC is rather similar in shape with those obtained from the Lund or Bowler models, and is rather different from distributions obtained in other models that have tails at low x (e.g. Peterson, Collins-Spiller). When the PC is the result of an analytic NLL computation, the NPC has to be extended beyond $x = 1$. This has not a physical meaning, It is directly related to the breakdown of the NLL QCD approach when x gets close to 1, and is necessary in order to compensate for the unphysical behaviour of the PC in this region. The fact that the NPC extends into a non-physical region implies that it cannot be described by any hadronic modelling, in this situation. In the two perturbative approaches that have been studied, it happens that the NPC has a similar shape, being simply translated to higher- x values in the case of analytic NLL QCD, illustrating the ability of this approach to account for softer gluon radiation than with a parton shower generator. The NPC extracted in the proposed way can then be used in another environment than e^+e^- annihilation, as long as the same parameters and methods are taken for the evaluation of the PC. Consistency checks, on the matching between the measured and predicted b -fragmentation distribution, can be defined which provide information on the determination of the PC itself.

2 Excited b -Hadron States

A new analysis from DELPHI concerning the spectroscopy of excited B states from the LEP data set of the years 1992-98 is reported⁷. Results are still preliminary. In this analysis the distribution of the variable $Q = m(B^{(*)}\pi) - m(B^{(*)}) - m(\pi)$ is considered. The background shape is extracted from data, and therefore the dependence on Monte Carlo is strongly reduced. The method is based on the use of two data samples which are, respectively, enriched and depleted in signal events. The background shape is determined directly from data. The two data samples are fitted simultaneously by a sum of two functions: one for signal and the other for background (Figure 3). The production rate of narrow $B_{u,d}^{**}$ states - assuming that they can be described by

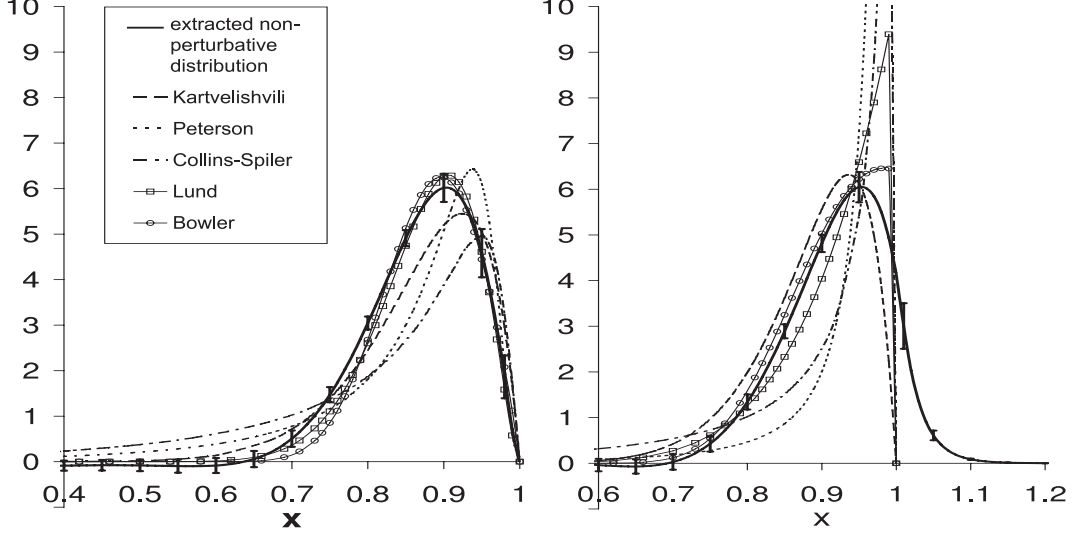


Figure 2: Comparison between the directly extracted non-perturbative component (thick full line) and the model fits on ALEPH's data. Left: the perturbative QCD component is taken from JETSET. Right: the theoretical perturbative QCD component is used.

a single Gaussian distribution- is measured to be:

$$P_b(B_u^{**})_{narrow} + P_b(B_d^{**})_{narrow} = 0.098 \pm 0.007 \pm 0.012. \quad (1)$$

Data suggest also the presence of broad states. The new measured rate, for narrow states, differs markedly from the one of $\sim 20\%$ usually reported. Nevertheless it is compatible with the measured production rate for narrow D^{**} states in c -jets. For B_s^{**} and $\Sigma_b^{(*)}$ upper limits on the production rates are obtained: $P_b(B_s^{**}) < 0.015$, $P_b(\Sigma_b^{(*)}) < 0.015$, at 95% confidence level, which supersede previous DELPHI results on these states.

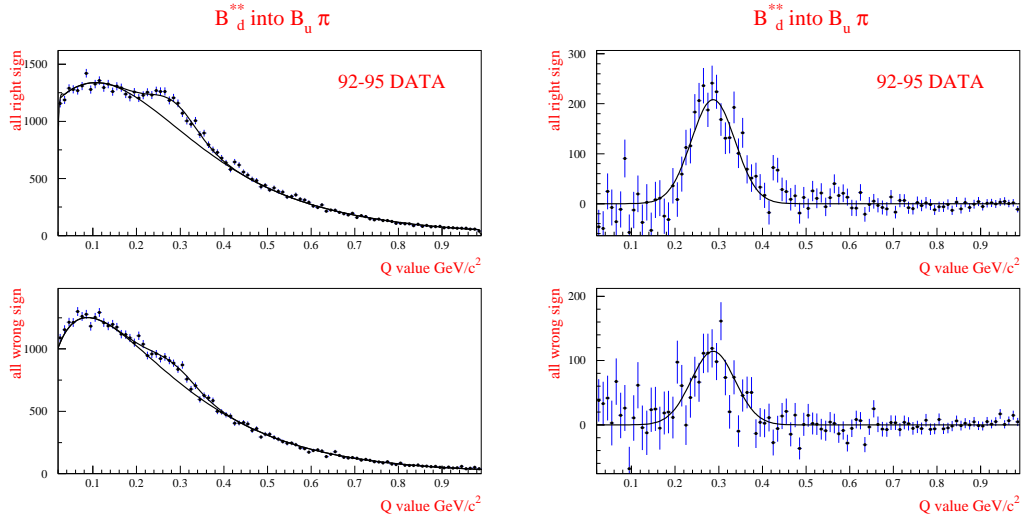


Figure 3: The Q distributions for the \overline{B}_d^{**} signal enriched (top) and background enriched (bottom) samples. The result of the fit is superimposed. On the right, the Q distributions after subtraction of the fit result for the background.

3 Branching Fractions of the b-Quark into Neutral and Charged b-Hadrons

The production fractions of charged and neutral weakly decaying b -hadrons in b -quark events have been measured with the DELPHI detector⁸. An algorithm has been developed, based on a neural network, to estimate the charge of the weakly decaying b -hadron by distinguishing decay particles from their fragmentation counterparts. From the data taken in years 1994 and 1995, the fraction of positively charged b -hadrons has been measured to be: $f^+ = (42.06 \pm 0.81(stat.) \pm 0.91(syst.))\%$. Subtracting the rates for charged Ξ_b^+ and $\bar{\Omega}_b^+$ baryons gives the production fraction of B^+ mesons: $f_{B^+} = (40.96 \pm 0.81(stat.) \pm 1.14(syst.))\%$. This is at present the most accurate measurement available.

4 Charged Particle Multiplicities

The mean charged particle multiplicities have been measured separately for $b\bar{b}$, $c\bar{c}$ and light quark ($u\bar{u}$, $d\bar{d}$, $s\bar{s}$) initiated events produced in e^+e^- annihilations at LEP. The data were recorded with the DELPHI⁹ and OPAL¹⁰ detectors at energies above the Z^0 peak, up to 206 GeV, corresponding to the full statistics collected at LEP1.5 and LEP2. The difference in mean charged particle multiplicities for b and light quark events, δ_{bl} , measured over this energy range is consistent with an energy independent behaviour, as predicted by a QCD calculation within the Modified Leading Log Approximation (MLLA)¹¹, based on coherence of gluon radiation. It is inconsistent with the prediction of a more phenomenological approach, the naive model¹², assuming the additional multiplicity accompanying the heavy quark to be emitted incoherently. Lower energy measurements could not discriminate between the two approaches. The combined OPAL and DELPHI results yield at average energies close to 196 GeV $\delta_{bl} = 3.44 \pm 0.40(stat.) \pm 0.89(syst.)$ and $\delta_{bl} = 4.26 \pm 0.51(stat.) \pm 0.46(syst.)$, respectively. These measurements, together with those from lower energy experiments, are presented in Figure 4.

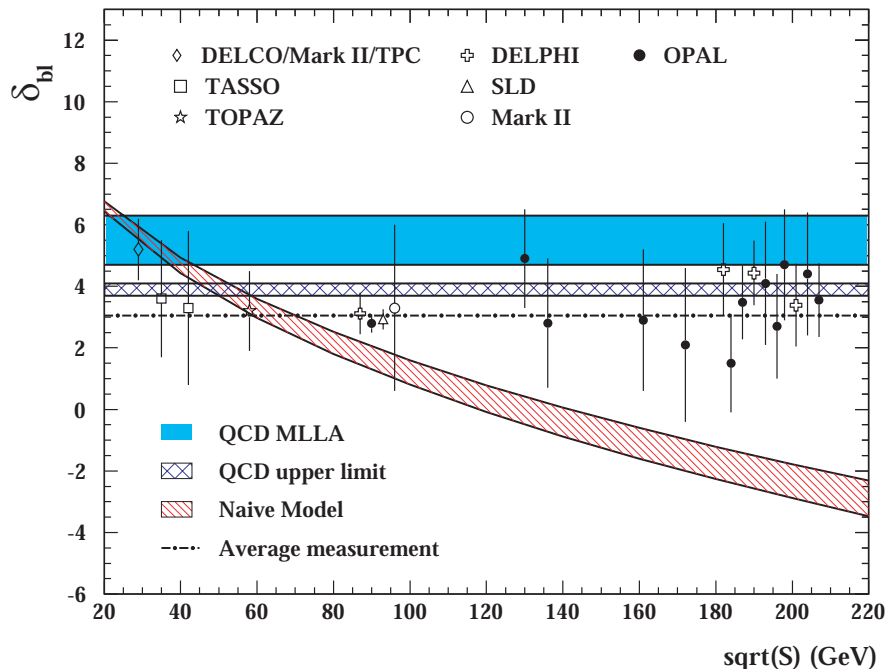


Figure 4: δ_{bl} as a function of the centre-of-mass energy from DELPHI, OPAL and lower energy experiments. The original MLLA prediction is shown as a shaded area to include the errors of experimental origin on this prediction, not including missing higher order corrections. The crosshatched area corresponds to the QCD upper limits. The single hatched area represents the naive model prediction.

5 Multiplicities in 3 Jet events

Data collected by the DELPHI detector have been used to determine the charged hadron multiplicity in three jet events ($q\bar{q}g$). The multiplicity has been measured in a cone of 30° opening angle perpendicular to the event plane. This cone multiplicity is noted $N_{ch}(30^\circ)$. In ¹³ a prediction is made, based on the assumption of coherent gluon radiation, relating the multiplicity $N_{\perp}^{q\bar{q}g}$ in cones perpendicular to the event plane in 3 jet events to the multiplicity $N_{\perp}^{q\bar{q}}$ in cones perpendicular to the event axis in 2 jet events:

$$N_{\perp}^{q\bar{q}g} = r \cdot N_{\perp}^{q\bar{q}} \quad (2)$$

The function r depends on the colour factors and the interjet angles (θ_{qg} , $\theta_{\bar{q}g}$, $\theta_{q\bar{q}}$):

$$r = \frac{C_A}{4C_F} \left[(1 - \cos \theta_{qg}) + (1 - \cos \theta_{\bar{q}g}) - \frac{1}{C_A^2} (1 - \cos \theta_{q\bar{q}}) \right] \quad (3)$$

The measured points are shown in Figure 5. They have been fitted using a linear function of the form: $a + b(r - 1)$. The values for a and b are also shown on the plot. They are compatible with each other and with the previously measured value $N_{\perp}^{q\bar{q}}(30^\circ) = 0.593 \pm 0.001$. Therefore they support the first order prediction of Equation 3 based on the coherence of gluon radiation.

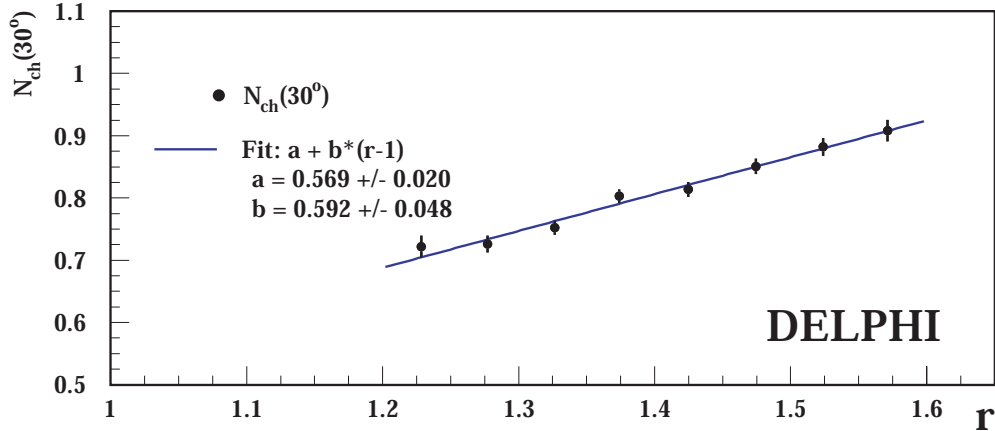


Figure 5: $N_{ch}(30^\circ)$ as a function of r measured by DELPHI and a straight line fit (preliminary).

6 Production Rates of ω and η Mesons

A new measurement of the inclusive production of the $\omega(782)$ and η mesons in hadronic Z^0 is available from ALEPH ¹⁴. The analysis is based on 4 million hadronic Z^0 decays recorded between 1991 and 1995. The production rate for $x_p = p_{meson}/p_{beam} > 0.05$ is measured in the $\omega \rightarrow \pi^+\pi^-\pi^0$ decay mode and found to be $0.585 \pm 0.019(stat.) \pm 0.033(syst.)$ per event. Inclusive η meson production is measured in the same decay channel for $x_p > 0.10$, obtaining $0.355 \pm 0.011(stat.) \pm 0.024(syst.)$ per event. These results are compatible with previous observations from L3 ¹⁵ and OPAL ¹⁶.

Acknowledgments

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